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Report to the Scientific Director

NATURE, INTENSITY, AND DISTRIBUTION OF FALL-OUT FROM MIKE SHOT

By

W. B. Heidt, Jr., LCDR, USN
E. A. Schuert
W. W. Perkins
R. L. Stetson

U. S. Naval Radiological Defense Laboratory
San Francisco, California

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CHAPTER 1

INTRODUCTION

The gamma-radiation hazard associated with radioactive debris from nuclear explosions constitutes an important capability of atomic weapons. The degree to which this capability can be exploited depends upon the magnitude of the militarily significant gamma-radiation fields produced and upon the ability to predict the location and extent of these fields. The phenomenon, commonly referred to as fall-out, varies with weapon yield and conditions of detonation. The present work proposes to extend the knowledge of such variations by investigating the fall-out material from Mike shot, Operation Ivy. The information derived will be useful for both offensive and defensive planning.

1.1 PREVIOUS FALL-OUT STUDIES

Fall-out from surface and subsurface nuclear detonations has been documented at previous test programs. The phenomenon was first observed after the detonation of the Alamogordo device in 1945.[1] Since that time it has become well established that the gamma hazard resulting from fall-out must be seriously considered as a problem of military significance for all types of detonations except the air burst.* Fall-out was first fully documented at Operation Jangle, but limited data were obtained at Operations Crossroads and Greenhouse.

1.1.1 At Operation Greenhouse

The fall-out study conducted at Operation Greenhouse revealed significant residual contamination from the Dog and Easy tower shots. This investigation was the first comprehensive study of fall-out forecasting.[2] These forecasting techniques, together with the work of J. O. Hirschfelder,[3] are the basis for the theories presented in the discussion of the fall-out at Operation Ivy.

1.1.2 At Operation Jangle

The surface shot at Operation Jangle more nearly represented a miniature Mike shot than any previous detonation. Fall-out studies were made at this operation, and complete data were obtained to a distance of several miles from ground zero.[4] The results were used in planning for Operation Ivy, and certain data to be found herein were extrapolated from information gained from the fall-out studies of Operation Jangle.

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*An air burst is defined for the purposes of this report as an explosion detonated at an elevation of such height that the resulting fireball at no time touches the surface of the earth.

1.2 OBJECTIVES

The gathering of fall-out data from Mike shot was a logical extension of previous fall-out documentation. The nature of Mike shot, Operation Ivy, made the study of fall-out extremely important. The yield from this shot was expected to exceed by many times that from any previous detonation, and consequently the cloud and associated debris were expected to rise to much greater heights. The additional fact that the shot was to be a surface explosion indicated the possibility of serious fall-out over large areas.

The present work (Project 5.4a) was designed to accomplish the following specific objectives:*

1. To measure the amount, distribution, and particle size of radioactive fall-out following Mike shot at Operation Ivy.
2. To determine at a limited number of close stations the rate of arrival of inert liquid or solid materials and associated radioactive materials.
3. To determine the particle-size fractionation of the radioactive fall-out with time and distance.
4. To analyze the base surge, if formed, for activity and to correlate this information with the fall-out data.
5. To correlate the fall-out pattern obtained with that predicted from a knowledge of the meteorological conditions and atomic cloud behavior.
6. To calculate from the intensities of radiation from fall-out the radiation field levels which would have been observed if the fall-out had occurred over extended land areas.

REFERENCES

1. Los Alamos Scientific Laboratory, "The Effects of Atomic Weapons," pp. 270-275, U. S. Government Printing Office, Washington, 1950.
2. Charles E. Adams, Fall-out Phenomenology, Greenhouse Report, Annex 6.4, WT-4, August 1951.
3. Los Alamos Scientific Laboratory, "The Effects of Atomic Weapons," Appendix F, U. S. Government Printing Office, Washington, 1950.
4. I. G. Poppoff, Fall-out Particle Studies, Jangle Project 2.5a-2 Report, WT-395; also in Particle Studies, WT-371.

*Full attainment of the objectives of this project was not possible because of operational restrictions imposed at a late date. See Appendix D, Tab A (revised) to Appendix I to Annex V.

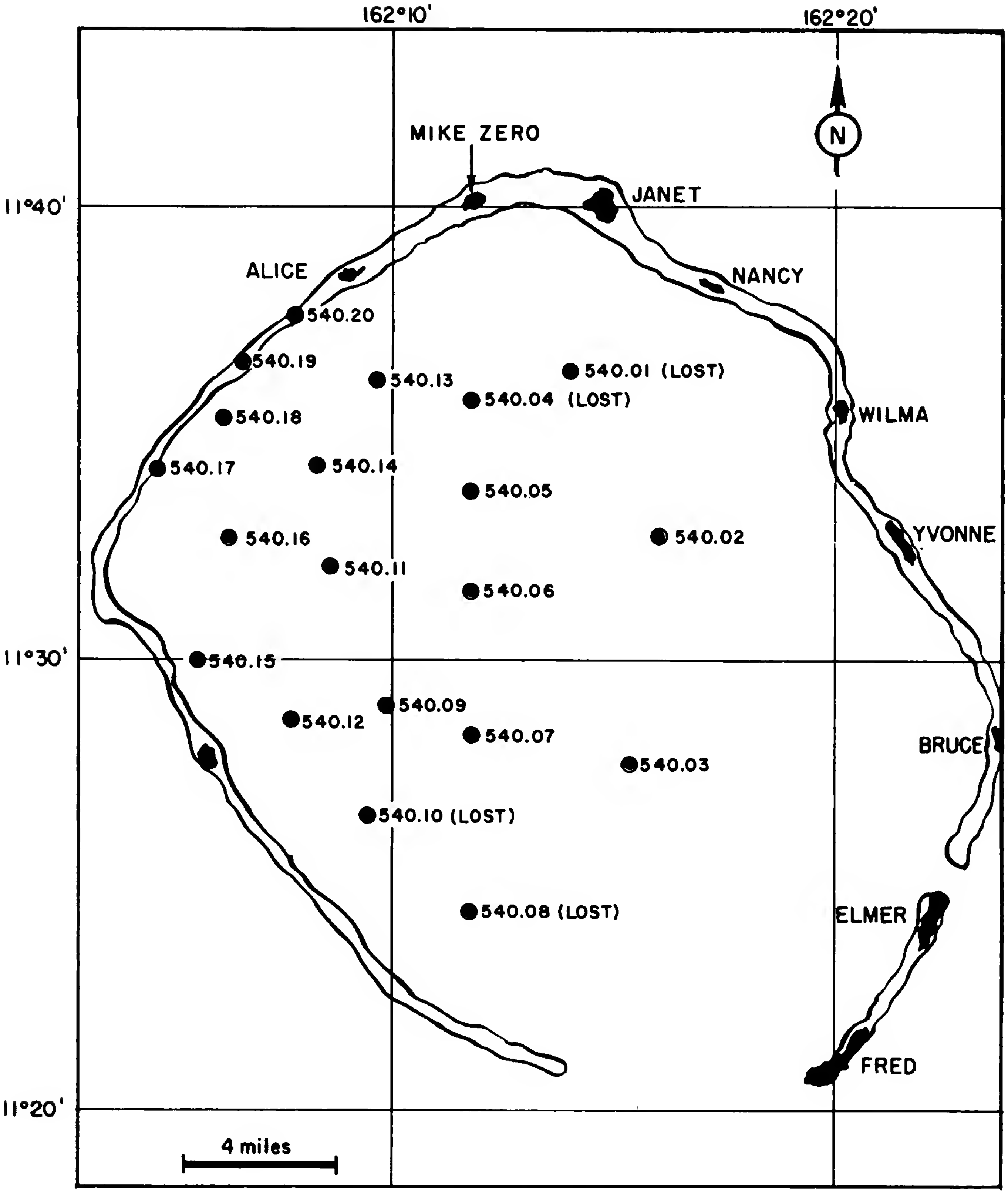

Fig. 2.1—Eniwetok Atoll stations.

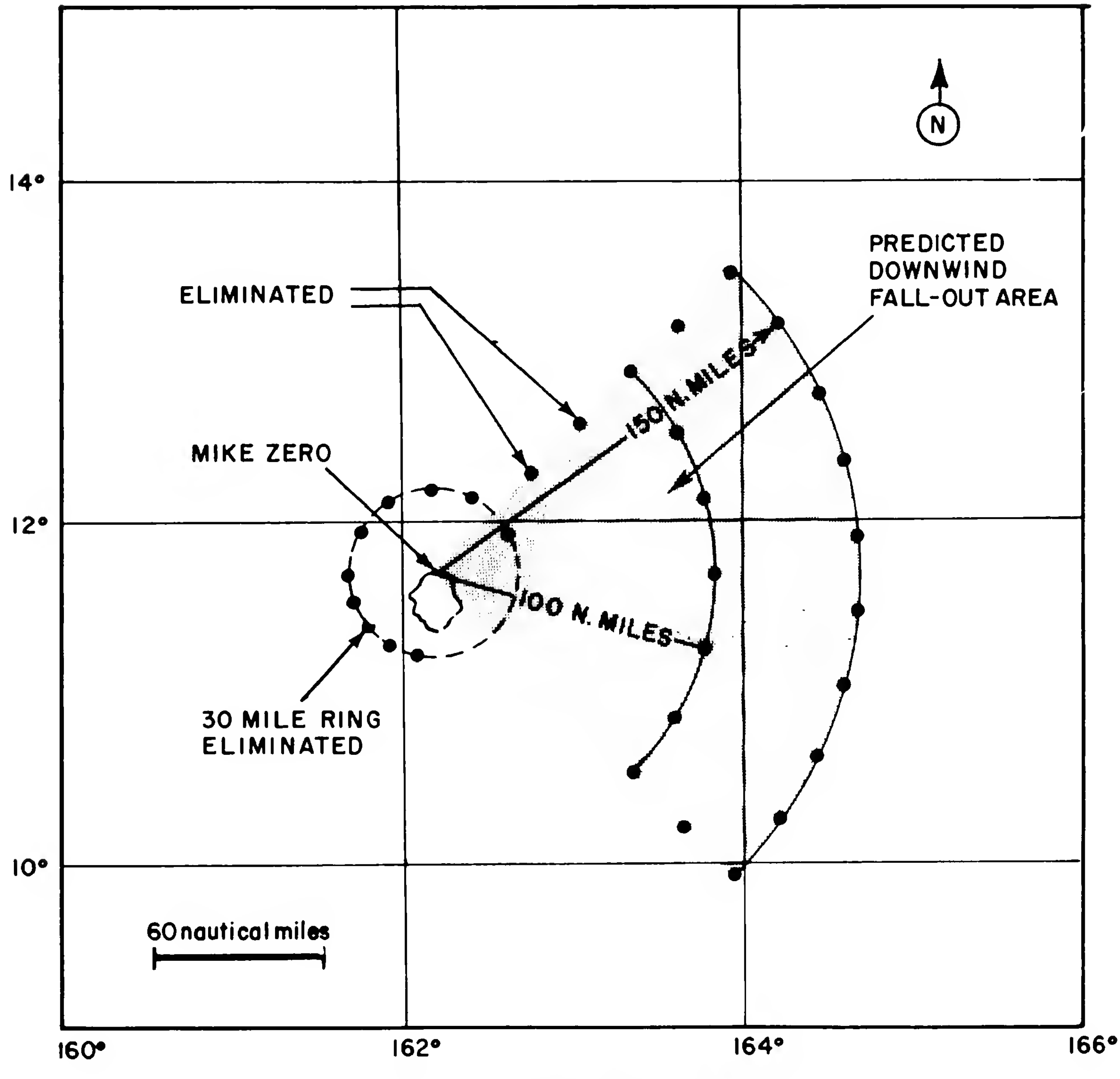

Fig. 2.3—Free-floating sea-station array.

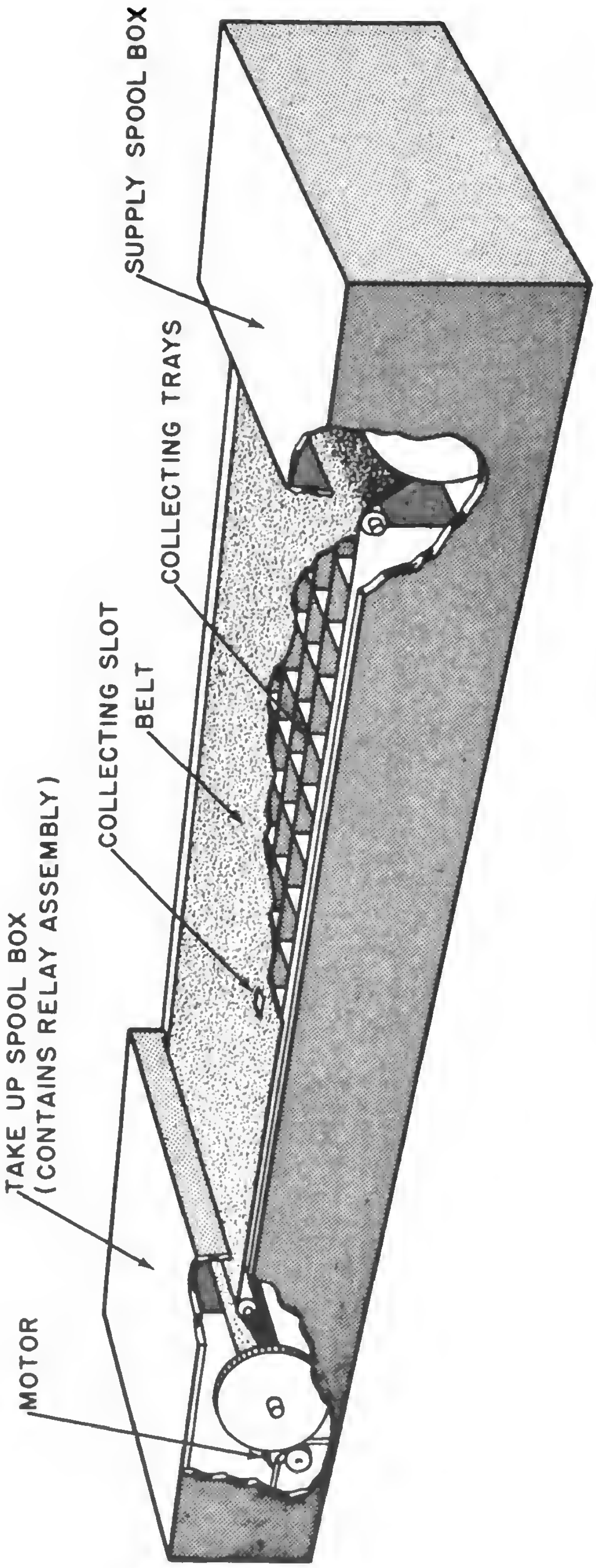

Fig. 3.2—Differential fall-out collector.

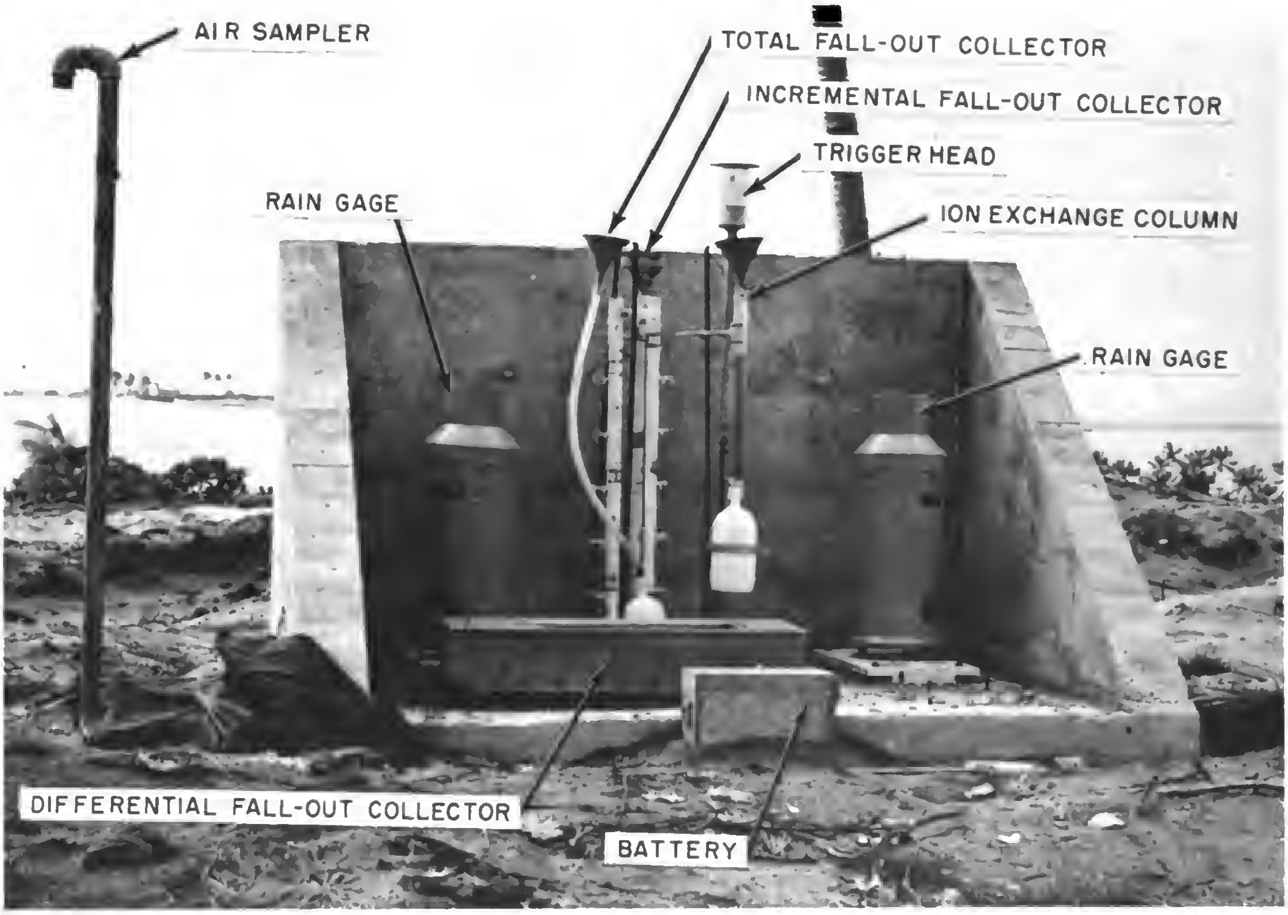

Fig. 3.8—A typical land station.

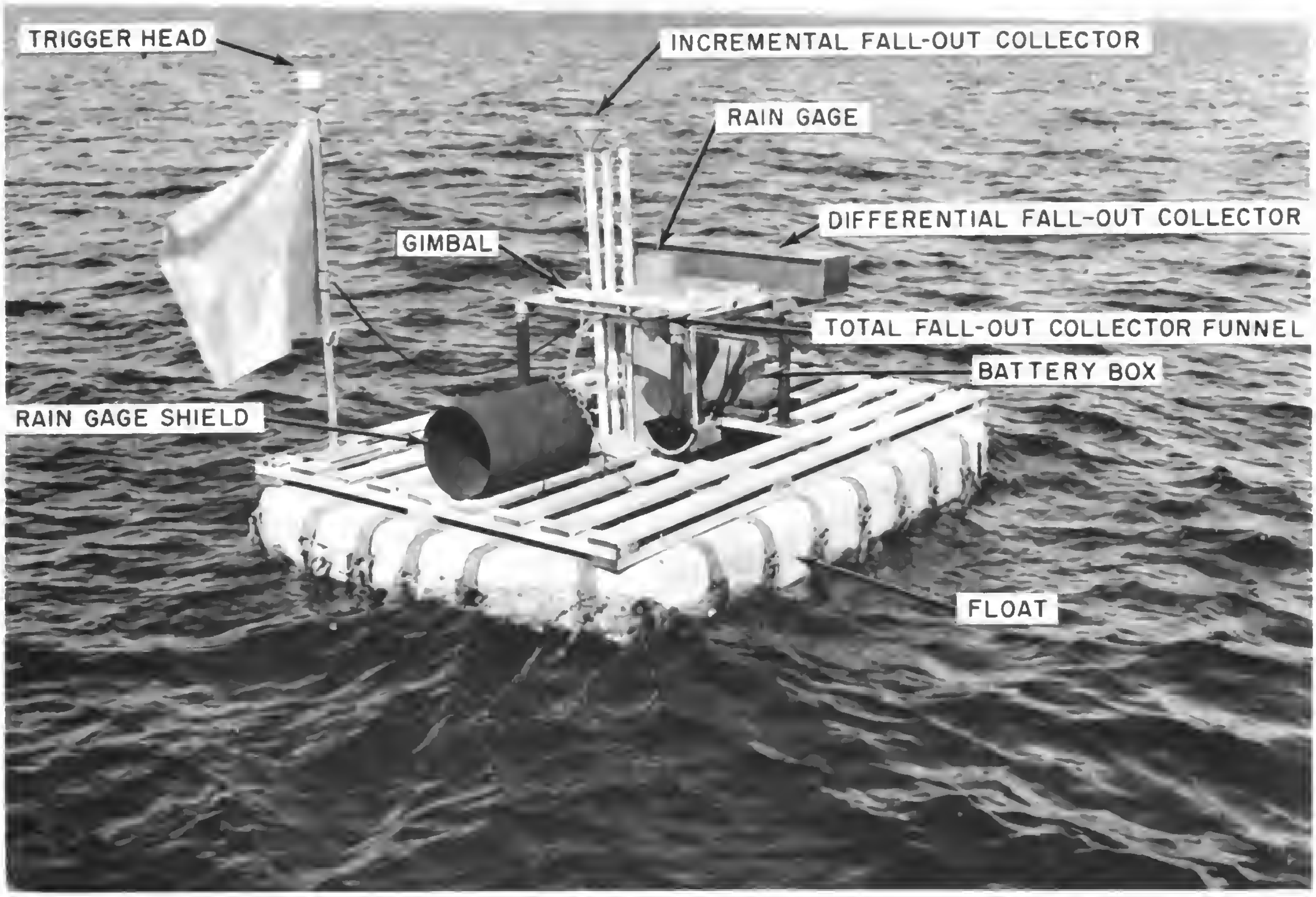

Fig. 3.9—A typical lagoon station.

3.10.5 Total Collector

This collector gave no trouble except that some fall-out adhered to the collecting funnel.

3.10.6 Ion-exchange Collector

This collector was also trouble free, but, since work is still in progress on the effluent from these columns, no attempt to evaluate them is made.

3.10.7 Gum-paper Collectors

No difficulty was experienced in using these collectors. An excellent feature of the Kum-Kleen adhesive was that, upon exposure, the surface tended to become more tacky rather than drying.

3.10.8 Résumé of the Operation of the Instruments

Table 3.1 shows the disposition and performance of the instruments used at the land and lagoon stations at Eniwetok Atoll.

Table 3.1 — INSTRUMENTATION AT LAND AND LAGOON STATIONS AT ENIWETOK ATOLL

Station	Distance, ft	Total collector	Rain gage	Incremental collector	Differential collector	Trigger	Life float	Remarks
540.20	26,400			Funnel blown off			Moved onto reef	
540.13	27,050	OK	OK	1½ columns blown off	Belt pulled through	OK	Burned slightly	
540.04	26,400							Lost before shot
540.01	26,400							Lost before shot
540.19	33,000			OK			Moved onto reef	
540.14	39,600	OK	OK	OK	Belt jammed	OK	OK	
540.05	39,600	OK	OK	OK	Belt tore	OK	OK	
540.18	44,880	OK	OK	Valve open	OK	OK	OK	
540.17	47,520			OK			Moved onto reef	
540.02	52,800	OK	OK	OK	Belt stuck	OK	OK	
540.11	52,800	OK	OK	OK	Relay failed	OK	OK	
540.06	52,800	OK	OK	OK	Belt stuck	OK	OK	
540.16	55,440	OK	OK	OK	OK	OK	OK	
540.09	68,640	OK	OK	OK	OK	OK	OK	
540.07	71,280	OK	OK	OK	OK	OK	OK	
540.15	72,000	OK	OK	OK	OK	OK	OK	Recovered off reef
540.12	73,920	OK	OK	OK	Belt stuck	OK	OK	
540.03	79,200							Lost
540.10	84,480							Lost before shot
540.08	95,040							Lost before shot
Alice	17,440							Equip. demolished
Janet	18,880	Broken	Broken	Broken	Belt stuck	OK		Equip. demolished
Nancy	33,800	OK	Damaged	OK	OK	Did not trigger		
Wilma	57,180	OK	OK	OK	Belt tore	OK		
Yvonne	75,520	OK	OK	OK	OK	Did not trigger		
Bruce	102,670	OK	OK	OK	OK	Did not trigger		
Elmer	115,060	OK	OK	OK	OK	OK		
Fred	124,580	OK	OK	OK	OK	Did not trigger		

CHAPTER 4

PRIMARY FALL-OUT

Primary fall-out following a nuclear detonation may be defined as the particulate which arrives at relatively early times and forms a well-delineated pattern downwind from ground zero. This fall-out has considerable military significance. The areas of primary fall-out, particularly from superweapons, are quite extensive, and many hours can elapse before the fall-out gamma field is completely defined.

4.1 GAMMA FIELD

The gamma field following Mike shot was well documented within the lagoon. An analysis of the wind profile at shot time indicated that the downwind fall-out lay over the open sea in a swath west-northwest to north of the island where the shot occurred. The data collected at Eniwetok on the Atoll islands and within the lagoon represent primarily the cross-wind pattern and a portion of the upwind region.

Observed Gamma Field. Comprehensive data on the gamma field were obtained within the bounds of Eniwetok Atoll and represent the cross-wind and upwind field. Figure 4.1, showing the gamma field, was compiled from island gamma-survey measurements and lagoon-station gamma-background readings corrected to values representative of the field that would be experienced on an extensive land mass. The gamma values indicated for the lagoon stations are the observed readings multiplied by 7. This multiplying factor results from the relation obtained at Operation Jangle between field gamma readings and gamma measurements of the fall-out from this field as read in a region having a gamma-free background.* [1] Cessation of cross-wind fall-out was at approximately M + 2 hr. The field reaches its maximum intensity† at about this time. Figure 4.1 represents the field at M + 2 hr. Extrapolation of gamma intensity to M + 2 hr was based on the ($t^{-1.2}$) decay law.

No activity was detected from gamma-survey measurements taken over the open water in the lagoon. An examination, primarily of the density of fall-out particulate, indicates that the particulate fell rapidly into the lagoon, where it settled on the bottom and left a zero field at the surface. There was some evidence that the lagoon currents carried a small amount of activity southward from the crater; this was measured by actual water sampling, but the activity had such low intensity that it did not generate a gamma field at the surface.

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*It is to be understood that the extension of Jangle relations to the soil and water conditions existing at Eniwetok is open to question. The data presented for the lagoon stations in Fig. 4.1 are simply the best approximations.

†As indicated on the Project 5.3 fall-out gamma time-intensity records.

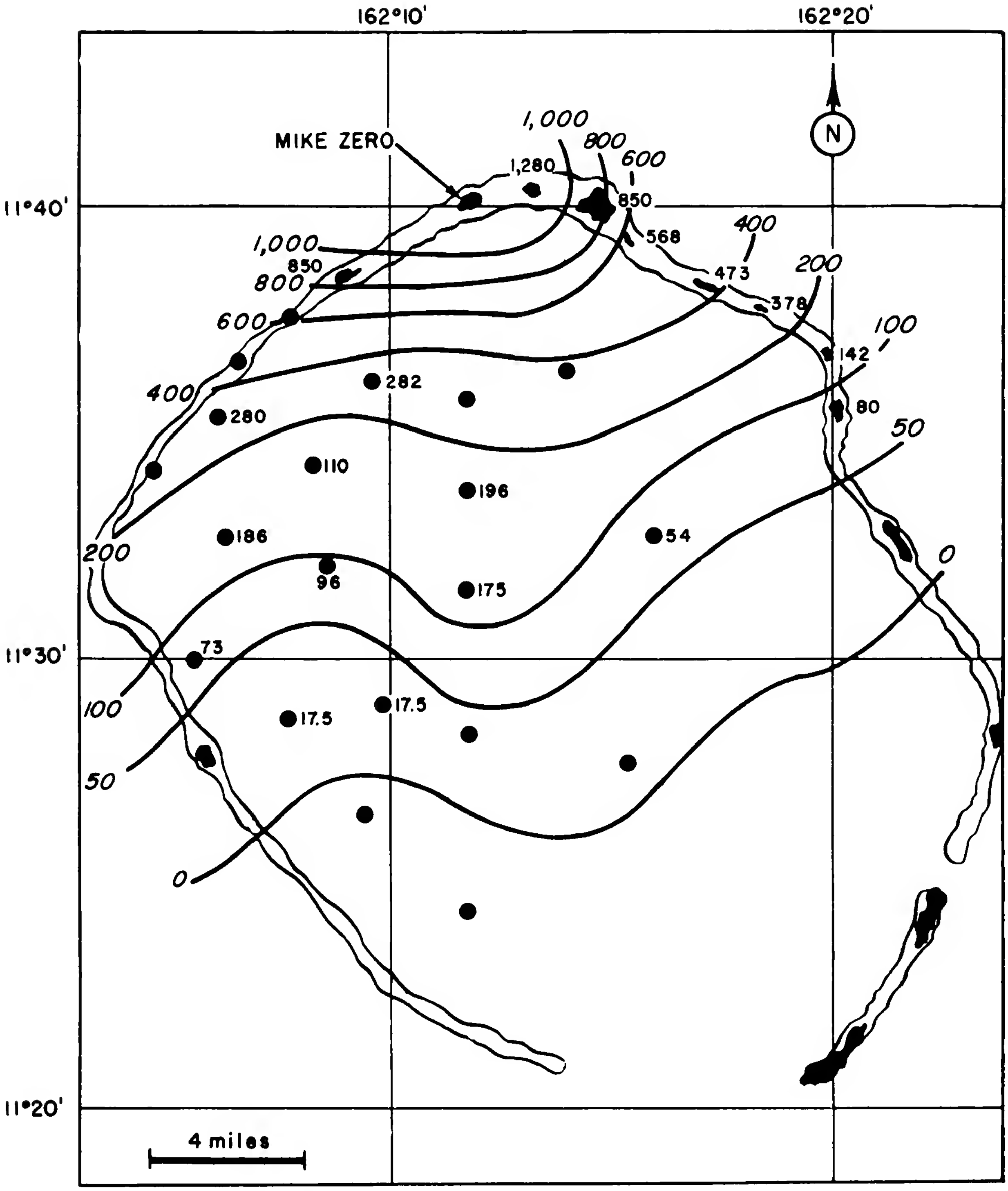
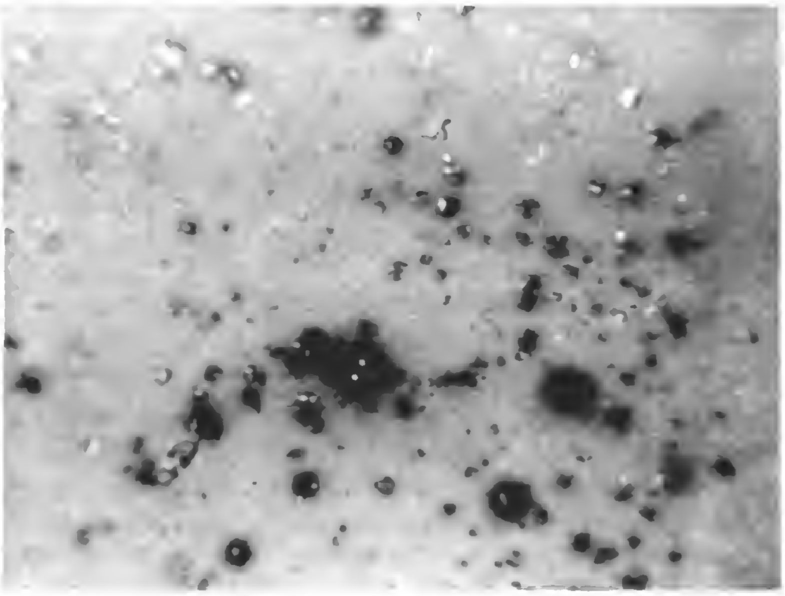
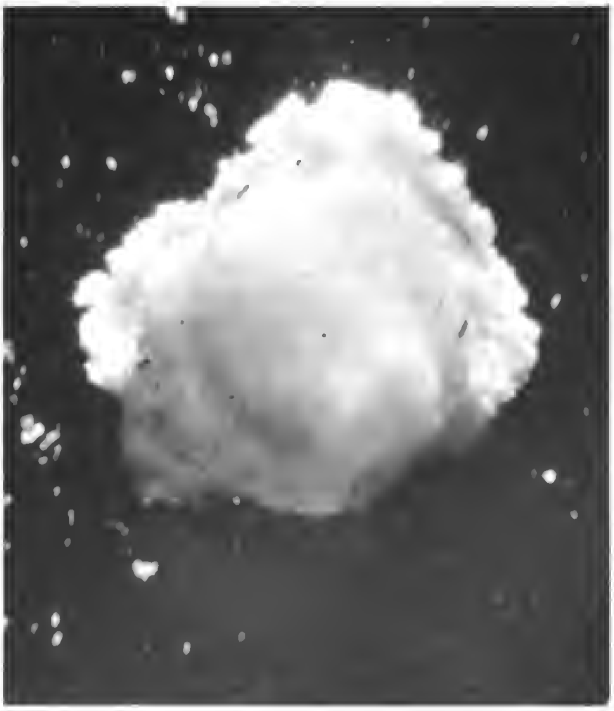


Fig. 4.1—Fall-out gamma pattern at 2 hr as would be experienced on a land mass (r/hr).



1,000
MICRONS

Fig. 4.2—Particles collected by a differential fall-out collector. (Note darkened area around the radioactive particle.)



1,000
MICRONS

Fig. 4.3—Plan view of a typical fall-out particle deposited on life-float decking.

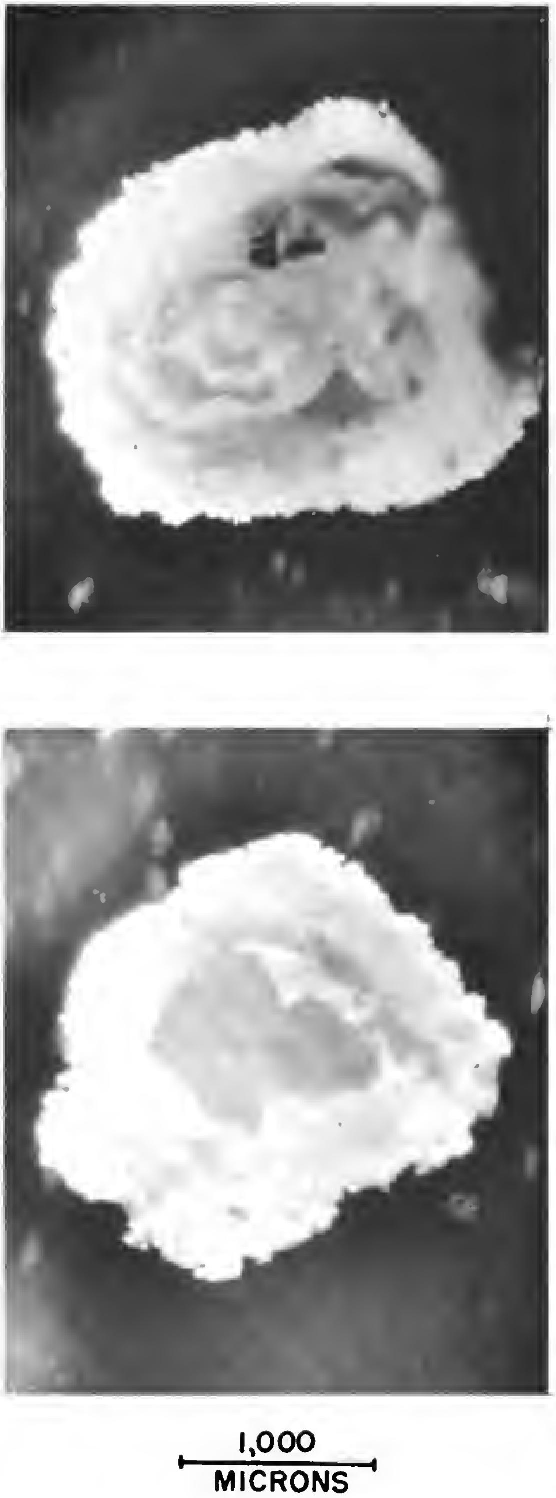


Fig. 4.4—Inverted view of typical particles removed from life-float decking.

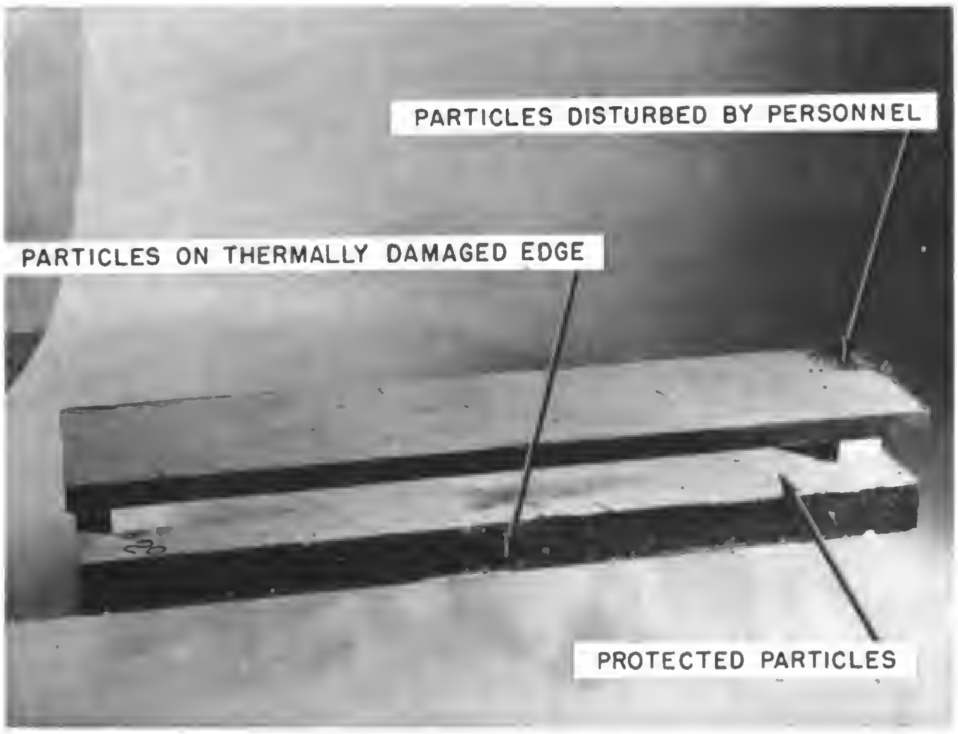


Fig. 4.5—Typical life-float section.

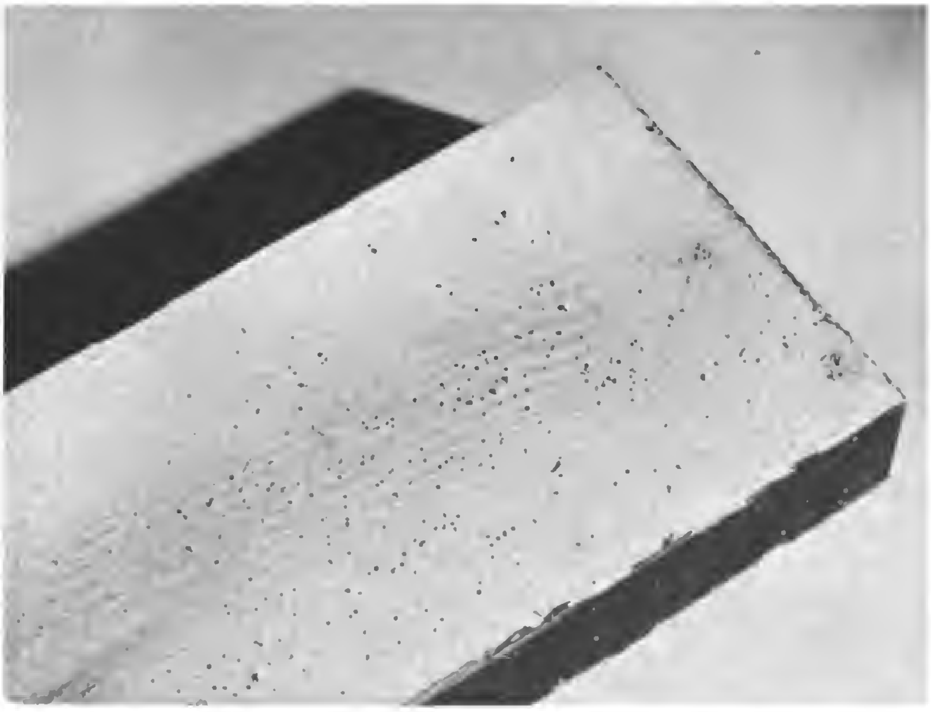


Fig. 4.6—Particle deposition on life-float decking (lower deck of Fig. 4.5).

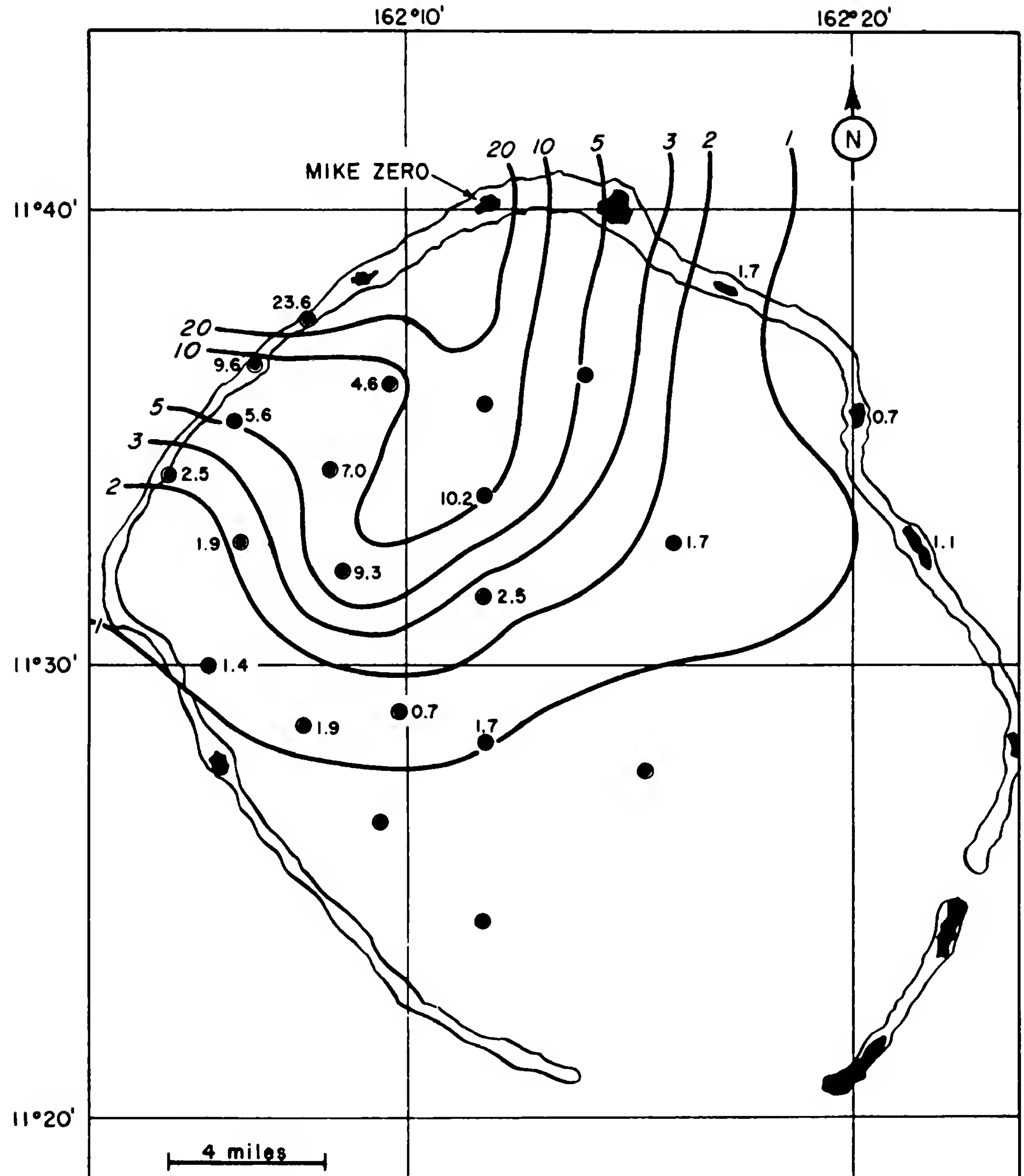


Fig. 4.8—Mass distribution of fall-out (g/sq ft).

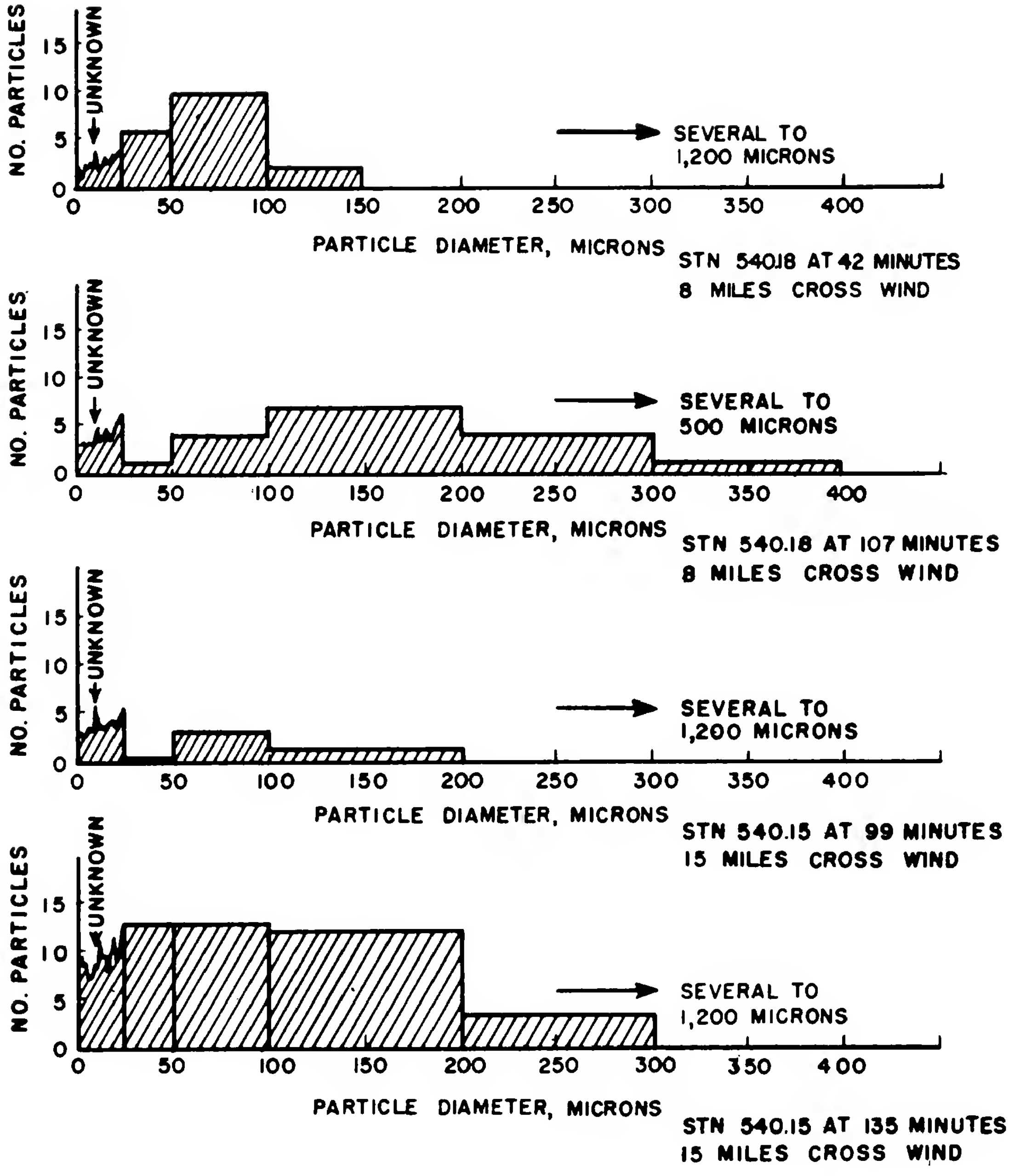


Fig. 4.10—Size distribution of radioactive particles as a function of time and distance.

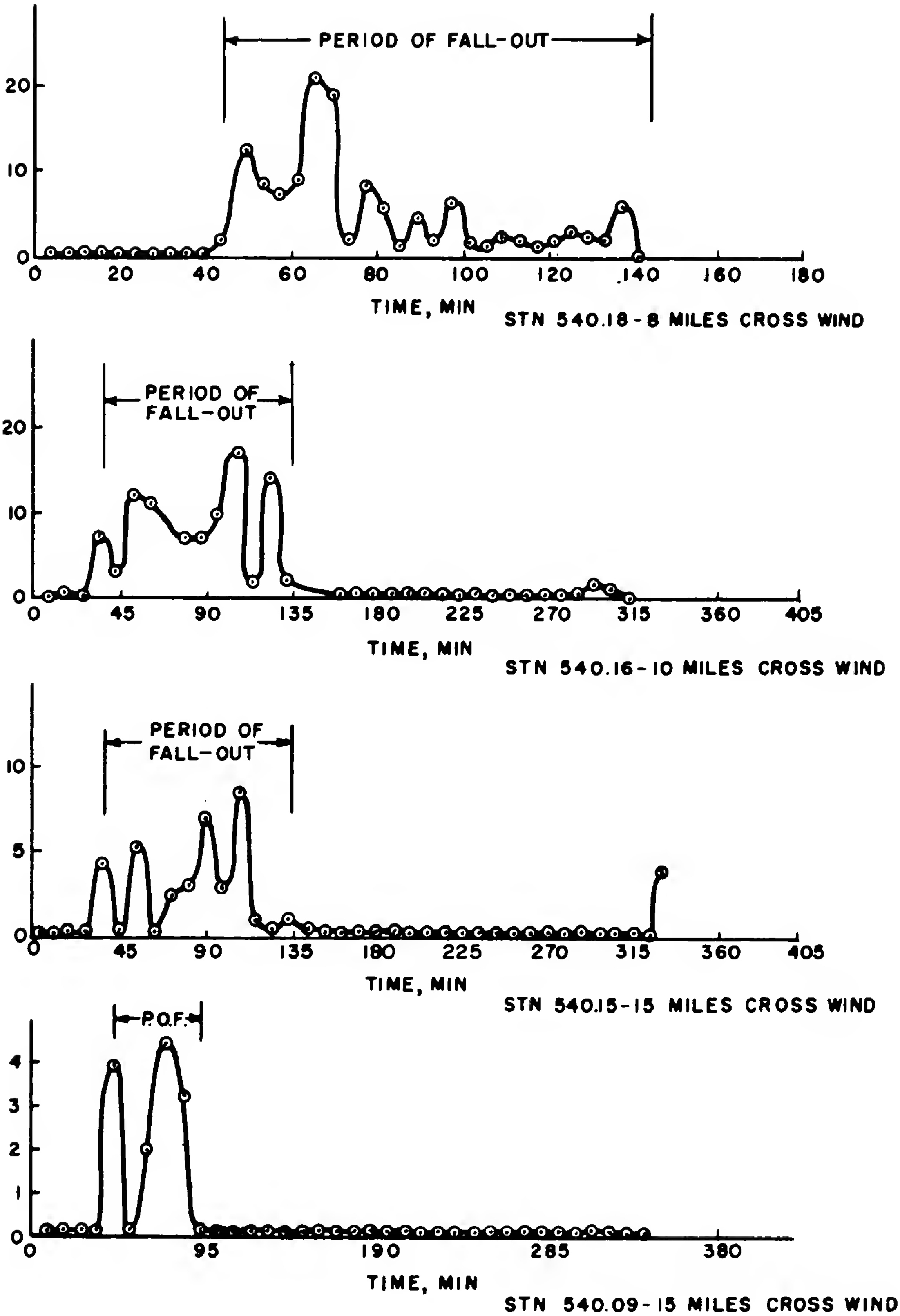


Fig. 4.11—Periods of primary fall-out at different stations.

shown in Fig. 4.11. Stations 540.15 and 540.09 were both located at 15 miles, but at different azimuths from ground zero (see Fig. 2.1 for location).

4.5.1 Arrival of Fall-out

It is most interesting to note that the cross-wind arrival time was completely independent of distance from ground zero. At the four stations from 8 to 15 miles, the fall-out began at +40 to +45 min. This suggests a delivery mechanism independent of winds (Chap. 6).

Table 4.3—SIZE DISTRIBUTION OF RADIOACTIVE FALL-OUT PARTICLES

Station	Distance cross wind, miles	Period of fall-out	Size distribution, μ: 25 to 50	50 to 100	100 to 200	200 to 300	300 to 400	Remarks
540.20	5.0	Early	4	8	14	5	7	Several particles to 5000 μ
540.18	8.0	Early	6	10	2			Several particles to 1200 μ
540.18	8.0	Middle	1	4	7	4	1	Several particles to 500 μ
540.17	10.0	Middle	1	2	10	1		Several particles to 1000 μ
540.16	10.0	Early	9	23	1	3		
540.15	15.0	Middle	0	2	1			Several particles to 1200 μ
540.15	15.0	Late	13	13	12	3		Several particles to 1200 μ

4.5.2 Duration of Fall-out

The four stations fixed the duration of fall-out at something less than 2 hr, with three of these stations experiencing exactly the same duration. Station 540.09, to the east of 540.15, shows the cessation of the fall-out to be at 0 + 95 min, a somewhat earlier time than the time of 0 + 144 min experienced by the other three stations.

4.5.3 Distribution of Activity with Time

Figure 4.11 shows the randomness of the time distribution of fall-out within the period in which it occurred. All the stations experienced several maxima and minima. These peaks and valleys show no correlation between time and distance. Since the samples were collected over limited areas, the levels of activity shown in Fig. 4.11 are not too representative.

REFERENCES

1. I. G. Poppoff, Fall-out Particle Studies, Jangle Project 2.5a-2 Report, WT-395; also in Particle Studies, WT-371.
2. U. S. Naval Radiological Defense Laboratory Report on High Explosive Model Studies (in preparation).

CHAPTER 6

METEOROLOGICAL CONSIDERATIONS AND FORECASTS OF FALL-OUT

Knowledge of the mechanism of the fall-out phenomenon is necessary as a first step in the development of forecasting techniques that will satisfactorily define the gamma field created by the residual radioactive debris from a nuclear detonation. Fall-out gamma fields of military significance are known to develop with surface and underground or underwater nuclear explosions, and the problem of fixing both the location and extent of the resultant radiation field is paramount for either offensive or defensive operations. Solution of this problem requires knowledge of the shot location, an estimate of the resulting cloud height, and the wind speed and direction to an elevation equal to the height of the explosion cloud.

6.1 THEORIES OF FALL-OUT MECHANISM

J. O. Hirschfelder's analysis[1] satisfactorily explains the mechanism of fall-out, except for the area immediately surrounding ground zero at Operation Ivy.

The theory developed by Charles E. Adams[2] accounts for the phenomenology of the fall-out in the area in the immediate vicinity of ground zero.

It is believed that these theories in their respective areas accounted for the fall-out phenomena accurately at Operation Ivy.

6.2 PRIMARY FALL-OUT

No data were collected downwind from ground zero. Figure 6.1 represents the downwind fall-out area as defined by the Hirschfelder analysis.

The cross-wind data showing the arrival time to be independent of distance can be satisfactorily explained by the vertical-circulation theory as explained by Adams in the Greenhouse fall-out studies. If a cloud chimney 5 miles in diameter is assumed to contain rising air currents, there is reason to believe descending currents exist around this upward convection column out to a distance equal to several column diameters. This vertical circulation is analogous to the circulation around a thunderstorm. A subsidence of this type would deposit particulate of heterogeneous mixture out to approximately 15 miles, and the time of deposition would be independent of distance.

Therefore the primary fall-out pattern is believed to have developed by two separate and distinct mechanisms: first, a subsidence extending out to several cloud diameters and, second, a downwind pattern determined by particle settling rates and the wind profile. This downwind pattern is based on the assumption that the particulate source is the cloud chimney from the

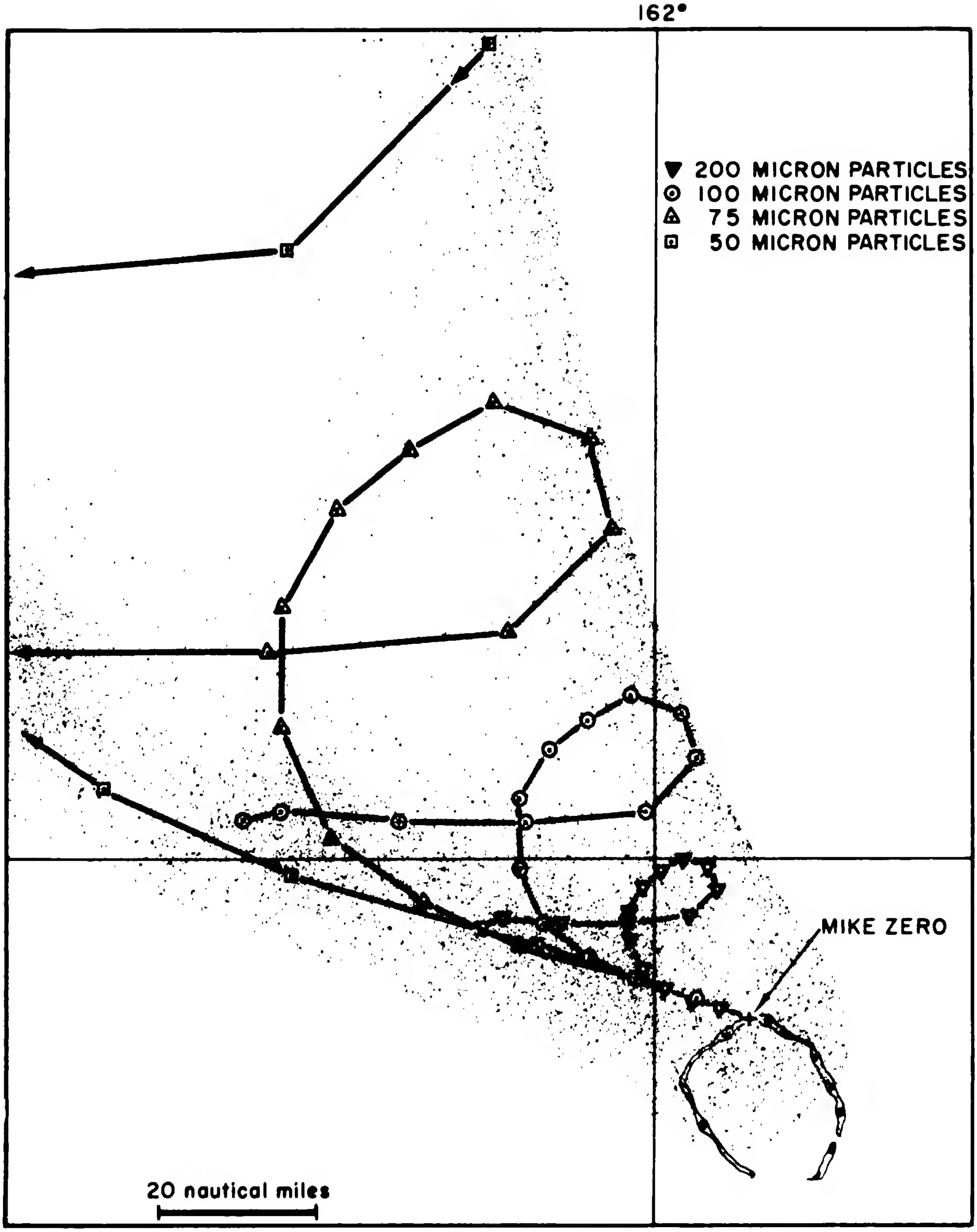


Fig. 6.1—Predicted area of primary fall-out.

surface to the cloud's maximum elevation, with a heterogeneous particle-size mixture existing throughout. The points of arrival of particle sizes from all elevations define the downwind pattern with respect to both area and time of arrival.

6.3 SECONDARY FALL-OUT

The winds in the Marshall Islands area above 90,000 ft are predominantly from the west at the time of the year of Operation Ivy.[3] The cloud from Mike shot rose to a height greater than 100,000 ft and was observed to move to the east. The few winds above 90,000 ft observed during the operation by the task force Weather Central were from the west.

The arrival time of the secondary fall-out can be satisfactorily explained by assuming that the particulate originated in the uppermost portion of the cloud, carried eastward by the stratospheric winds. Since the particulate settled into the troposphere somewhere east of the Marshall Islands area, an examination of the troposphere wind pattern during the days following the detonation showed that the particulate would be carried back westward and deposited as secondary fall-out in the area investigated.

6.4 THE EFFECT OF VERTICAL MIXING

The arrival time of small particulate at distances beyond the area of subsidence has defied explanation by particle settling rates. This failure is especially evident when considering arrival times of secondary fall-out. It is suggested that for particles whose diameter and density establish slow settling rates the effect of vertical mixing in the atmosphere becomes the primary mechanism determining their deposition.

REFERENCES

1. Los Alamos Scientific Laboratory, "The Effects of Atomic Weapons," Appendix F, U. S. Government Printing Office, Washington, 1950.
2. Charles E. Adams, Fall-out Phenomenology, Greenhouse Report, Annex 6.4, WT-4, August 1951.
3. C. E. Palmer, The Central Pacific Project, First Report, Institute of Geophysics, October 1951.

CHAPTER 7

SUMMARY

Prediction of the downwind area of primary fall-out with a high degree of confidence early enough to establish a selective station array to cover the area cannot be satisfactorily accomplished. The limited climatological data available for the Marshall Islands indicate the most probable direction of the winds aloft during the fall and winter months to be from the east for heights of approximately 20,000 ft and from the west for heights between 20,000 and 100,000 ft. However, the wind profile at shot time indicated that the primary fall-out following Mike shot was deposited to the northwest of Eniwetok Atoll. It is noteworthy that during the two weeks prior to shot time, the daily variation in the wind profile was of such magnitude that a 24-hr forecast of the fall-out area would have been in error in the majority of cases. However, if the winds aloft are known at the time of detonation, it is possible to predict quite accurately the distribution of ground contamination resulting from radioactive fall-out.

Observation of the documentary photography taken of Mike shot, Operation Ivy, indicated no evidence of a base surge following the detonation. Although the major portion of this film did not record surface phenomena, those portions documenting the surface of the lagoon after the event do not show a base surge.

The fall-out particulate, being primarily compounds of calcium, was peculiar to a coral atoll. The main contribution to the radiation field was the fission product mixture trapped within these particulates. The particle density was between 1 and 3 g/cu cm in the majority of cases and similar to that of many soils. Although there was not a great quantity of fall-out at any location, the individual particles were very active, some reading as high as 300 mr/hr of beta-gamma radiation 48 hr after shot time. The activity was easily leached from the particulate by the action of rain water. The particle reaction with the sulfate ions in sea water caused them to become hollow and to adhere to any surface they touched. This behavior is probably the most significant observation of the effect of the environment on the particles.

7.1 CONCLUSIONS

In summarizing the work done on this project, it is convenient to state the conclusions as they specifically apply to either the primary or secondary fall-out.

7.1.1 Primary Fall-out

The gamma-radiation field at the cessation of the primary fall-out varied from about 800 r/hr at 2 hr and 3 miles distance to 0 r/hr at a cross-wind distance of approximately 15 miles.

There was no residual radiation field over the open water of the lagoon. Evidently the radioactive particulate immediately settled to the bottom.

The gamma decay curve for the radioactive fall-out has a slope of approximately −1.2.

The fall-out was solid particulate made up of calcium hydroxide with a very thin layer of calcium carbonate on the outer surface. The fission products were trapped within the particulate.

Those particles that arrived in such an environment as sea-washed decking were slowly dissolved, with a resulting reprecipitation of the calcium ion by the sulfate ion which exists in comparatively high concentration in sea water. As a result of this phenomenon, many hollow particles formed and firmly adhered to all surfaces they touched.

The fission products readily leached from the particulate exposed to rain water. The leached activity was both ionic species and colloids.

The quantity of primary fall-out in the cross-wind direction varied from some value over 20 g/sq ft at 4 miles to 0 g/sq ft at 15 miles.

The particle diameters of the radioactive fall-out varied from less than 10 μ to greater than 5000 μ.

There was no particle-size fractionation with cross-wind distance and only meager evidence of any with time.

The cross-wind fall-out arrival time was entirely independent of distance from ground zero; duration of fall-out was approximately 1 to 2 hr.

There was a random distribution of activity with time at all stations in the cross-wind radiation field.

7.1.2 Secondary Fall-out

Secondary fall-out arrived over an extensive area of the Pacific around Eniwetok Atoll.

The period of secondary fall-out was several days at any one location, arriving from 2 to 5 days after the detonation.

None of the secondary fall-out was of military significance since a gamma dose rate of less than 10 mr/hr was noted at all collecting stations.

In no case was any of the secondary fall-out particulate over 25 μ in diameter.

The secondary fall-out arrived from an initial height greater than 80,000 ft.

7.2 RECOMMENDATIONS

Experience gained during the work on this project makes possible certain suggestions for consideration in the planning of future operations. The inability to predict the area of primary fall-out well in advance of shot time can be presumed to be definitely established. Consequently it is recommended that a 360° coverage of collecting stations be provided in future tests.

Furthermore the use of free-floating stations can be considered practical and highly desirable if a method for their positive location is provided. Whatever methods that are devised for locating the free-floating stations must not interfere with the task force security search patrol. Therefore it is recommended that a lightweight coded signaling device such as the British Ultra Air Sea Rescue beacon be installed on each of the free-floating stations.

Table B.3 — TOTAL ACTIVITY AND TOTAL MASS OF COLLECTED MATERIAL

Station	Total activity, c/m	Total activity on unit area, c/m/sq ft	Total mass on unit area, g/sq ft	Per cent of activity in solid
		Total Collectors		
540.02	0.34×10^8	1.73×10^8	1.57	33.0
540.05	0.97×10^8	4.94×10^8	0.46	68.0
540.06	0.14×10^8	0.71×10^8	1.52	19.2
540.07	0.06×10^8	0.31×10^8	1.68	42.5
540.09	0.49×10^8	2.49×10^8	0.26	80.4
540.11	0.41×10^8	2.09×10^8	9.35	36.4
540.12	0.22×10^8	1.12×10^8	0.28	44.0
540.13	12.26×10^8	62.44×10^8	4.22	75.3
540.14	1.72×10^8	8.76×10^8	1.01	59.3
540.15	0.32×10^8	1.63×10^8	1.41	33.4
540.16	0.87×10^8	4.43×10^8	1.14	59.7
540.18	13.15×10^8	66.97×10^8	4.64	86.8
540.20	0.06×10^8	0.31×10^8	23.6	14.5
Nancy	3.18×10^8	16.20×10^8	1.66	83.3
Wilma	1.54×10^8	7.84×10^8	0.40	57.3
Yvonne	1.51×10^8	7.69×10^8	1.14	98.6
Elmer	3.36×10^5	17.11×10^5	0.09	5.9
Fred	2.00×10^4	10.19×10^4	0.005	100.0
Bruce	8.00×10^3	40.74×10^3	0.005	100.0
		Rain-gage Buckets		
540.02	2.30×10^8	6.59×10^8	1.68	86.6
540.05	19.06×10^8	54.60×10^8	10.2	97.5
540.06	6.93×10^8	19.85×10^8	2.54	86.1
540.07	1.48×10^8	4.24×10^8	1.56	95.0
540.09	1.37×10^8	3.92×10^8	0.68	88.0
540.11	6.97×10^8	19.97×10^8	3.82	95.1
540.12	0.44×10^8	1.26×10^8	1.88	72.2
540.13	41.09×10^8	117.72×10^8	4.60	90.1
540.14	12.81×10^8	36.70×10^8	7.0	96.7
540.15	1.66×10^8	4.76×10^8	0.73	89.8
540.16	6.77×10^8	19.40×10^8	1.95	80.8
540.17	5.83×10^8	16.70×10^8	2.52	73.3
540.18	8.21×10^8	23.52×10^8	5.63	78.0
540.19	23.81×10^8	68.21×10^8	9.6	96.0
540.20	28.39×10^8	81.33×10^8	5.35	60.5
Janet	13.12×10^8	37.59×10^8	4.85	92.4
Nancy	34.62×10^8	99.18×10^8	16.2	93.1
Wilma	1.29×10^8	3.70×10^8	0.67	86.0
Yvonne	0.17×10^8	0.49×10^8	0.79	94.0
Elmer	16.12×10^5	46.18×10^5	0.20	6.8
Fred	12.26×10^4	35.12×10^4	1.7	35.9